# Chapter 90
# Network Design of a Low-Power Parking Guidance System

**Ming Xia, Yabo Dong, Qingzhang Chen, Kai Wang, and Rongjie Wu**

**Abstract** A parking guidance system can help a driver quickly find an available parking space. Most currently available parking guidance systems require wire deployment in installation, thus entailing high installation costs. In this chapter, we discuss the network design of a low-power parking guidance system. We developed a tiered communication architecture including Wireless Sensor Network (WSN), General Packet Radio Service (GPRS) network and Internet to realize wireless parking space availability data transmission, and thus installation complexity can be greatly reduced. In order to reduce the battery replacement frequency of the WSN, we designed a power-minimized Medium Access Control (MAC) protocol. The proposed MAC protocol divides one network working cycle into four dedicated intervals to realize robust network organization and energy-efficient data delivery. Experimental results showed that the proposed MAC protocol can extend the battery lifetime of the WSN to more than ten years. Based on the collected parking space availability data, we built a portable parking guidance terminal to let drivers locate available parking spaces conveniently.

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## 90.1 Introduction

Searching for an available parking space in urban areas is becoming more and more annoying to drivers. This is partly caused by the rapid increase of the number of cars in large cities, and partly by the lack of parking space availability information. In order to alleviate the problem, parking guidance systems, which detect and guide drivers to available parking spaces, were developed in recent years. However, many currently available parking guidance systems require communication wire to transmit parking space availability information [1], thus entailing high costs in system deployment. Researchers proposed to use Wireless Sensor Networks (WSNs) to realize full wireless deployments [2]. A WSN typically consists of a large number of low-power, low-cost wireless sensor nodes to collect, process and transmit data collaboratively. As a result, sensor nodes can be battery powered, and the deployment complexity can be greatly reduced. Current researches on applying WSNs to parking guidance systems have discussed sensor design [3], vehicle detection algorithm design [4] and parking space searching policy design [5]. Nevertheless, we found that communication strategies including communication architecture and protocols are also critical issues in system design. As a result, we will focus on the design of efficient communication architecture and protocols for parking space availability information transmission in this chapter. First, we will introduce our tiered communication architecture including WSN, General Packet Radio Service (GPRS) network and Internet to realize wireless and wide-area parking space availability information transmission. Then, we will present the design of a power-minimized WSN Medium Access Control (MAC) protocol to maximize the battery lifetime of parking space sensors. We chose battery lifetime maximization as our major optimization object because parking space sensors are installed on the ground and battery replacement is relatively difficult. In order to reduce maintenance costs, long battery lifetime is a must. After that, we will discuss system implementation on customized hardware and a portable parking guidance terminal based on smartphone to enable drivers to acquire parking space availability information at any place and any time. At last, the experimental deployment of the system at a parking lot verifies the effectiveness of the proposed network design.

## 90.2 Network Design

We developed a tiered communication architecture which integrates WSN, GPRS network, and Internet to meet the deployment requirement of parking space availability monitoring and parking guidance, as shown in Fig. 90.1.

*WSN*: The communication between parking space sensors and gateway nodes employs WSN technology. In order to maximize the battery lifetime of parking space sensors, we designed a power-minimized MAC protocol.

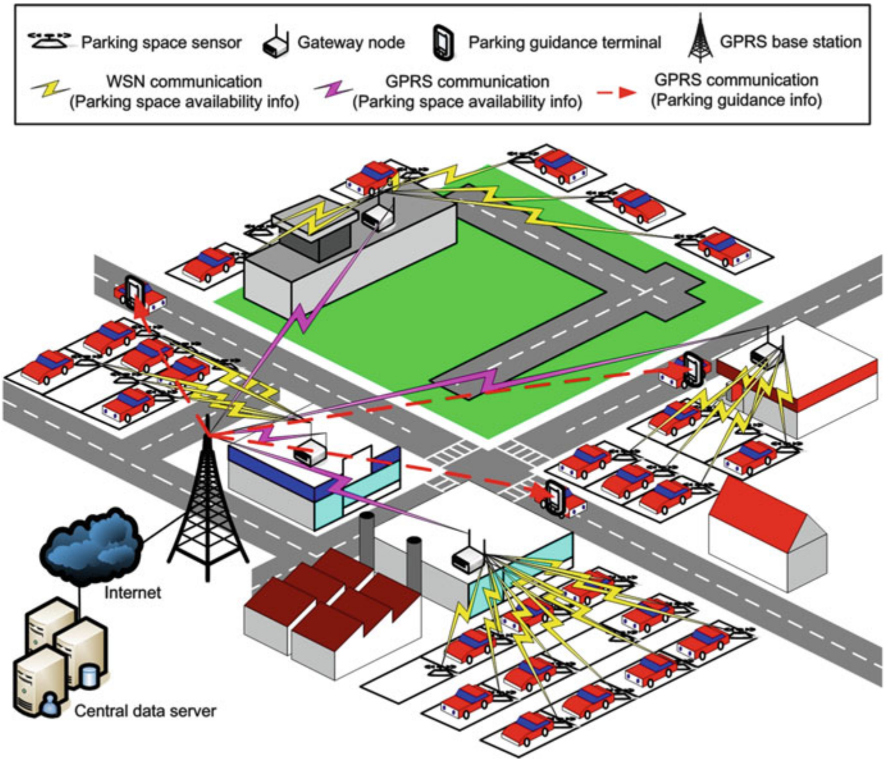


**Fig. 90.1** Communication architecture

*GPRS network and Internet*: The communication between gateway nodes and the central data server uses GPRS network and Internet to ensure the large coverage area. At the same time, central data server will send the parking guidance information to the portable parking guidance terminal through GPRS network and Internet.

We will then elaborate on the details of the MAC protocol design. One of the major tasks of our MAC protocol for WSNs is to reduce the power consumption of sensor nodes. The design principles of WSN MAC protocols can be roughly categorized as either contention-based or Time Division Multiple Access (TDMA)-based. We chose to employ TDMA in our MAC protocol design because it does not suffer from collisions and thus can frequently achieve lower power consumption.

Generally, the gateway node is responsible for the establishment of the network, and the parking space sensors will select and join the "best" network established by one gateway node. The gateway node divides one working cycle into four intervals, including JOINING, TESTING, COLLECTING and UPLOADING, as shown in Fig. 90.2. In different intervals, the gateway node broadcasts different types of beacons periodically to notify parking space sensors.

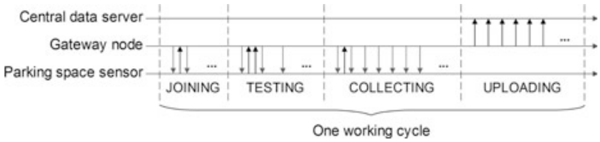


**Fig. 90.2** Four intervals of the proposed MAC protocol

The proposed MAC protocol works as follows:

(1) A gateway node scans all usable channels one by one, and chooses one silent channel to establish the network.
(2) A parking space sensor scans all usable channels one by one when powered on. It records all beacons captured in scanning and compares the signal strength and will try to select the gateway node with the strongest signal strength to transmit parking space availability information. In order to notify the selected gateway node, the parking space sensor waits for the JOINING beacon from the selected gateway node and immediately replies a *JOINING_REQUEST* after the beacon. Here we use a simple Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) protocol to avoid collision.
(3) The gateway node that receives the *JOINING_REQUEST* will reply a *JOINING_CONFIRMATION* to the parking space sensor if it is able to adopt more sensors. In the *JOINING_CONFIRMATION*, the gateway node tells the parking space sensor the time slot assigned to it in the TESTING interval. If the gateway node is unable to adopt more sensors, it will reply a *JOINING_REJECTION* to the parking space sensor and the sensor will repeat step (2) and select another gateway node.
(4) A parking space sensor that receives the *JOINING_CONFIRMATION* will go sleep and wait for the time slot assigned to it to wake up in the TESTING interval. It will start testing (i.e., transmitting several packets to the gateway node and calculating the transmission success rate) immediately once it receives the TESTING beacon broadcasted by the gateway node. We designed a dedicated TESTING interval to ensure the communication quality between the parking space sensor and the selected gateway node because the received signal strength frequently cannot accurately reflect the link quality. If the transmission success rate is high enough, the parking space sensor will send a *REGISTERING_REQUEST* to the selected gateway node. Otherwise, it will go back to step (2) and select another gateway node.
(5) A gateway node that receives the *REGISTERING_REQUEST* will reply a *REGISTERING_CONFIRMATION* to the parking space sensor telling it the time slot assigned in the COLLECTING interval.
(6) A parking space sensor that receives the *REGISTERING_CONFIRMATION* will go sleep and wait for the time slot that is assigned to it to wake up in the COLLECTING interval. Once it wakes up and receives a COLLECTING beacon, it will transmit parking space availability information to the gateway node immediately. The gateway node will cache the received parking space availability information for uploading.

(7) In the UPLOADING interval, the gateway node uploads the received parking space availability information to the central data server via GPRS network.
(8) In the next round, a parking space sensor will only wake up in its time slot in the COLLECTING interval, and the COLLECTING beacon will be the time synchronization signal to avoid clock drifting. In order to conserve energy, the sensor will transmit data only if the state of the parking space (occupied/available) changed. Otherwise, the sensor only reports its state at a low frequency. If the sensor encounters continuous data transmission error, it will go back to step (2) to re-join a network.

## 90.3 Hardware Design

In this section, we will discuss the design of parking space sensors, gateway nodes and parking guidance terminal.

*Parking space sensor*. Our parking space sensor is directly installed on the ground of a parking space, and thus we designed a special robust and water-resistant enclosure for it. The design of the enclosure and its photo are given in Fig. 90.3. We chose an STMicroelectronics STM32F103 as microcontroller and an Atmel AT86RF212 as radio chip, which works on 700/800/900 Mhz. We chose a Honeywell HMC5883L geomagnetic sensor to monitor if the parking space is occupied. If there is car on the sensor, the earth's magnetic field will be changed, and we can monitor this event through measuring the output of the sensor.

*Gateway node*. The gateway node also adopts an STMicroelectronics STM32F103 as its microcontroller, and it has two radio chips, one is the 700/800/900 Mhz Atmel AT86RF212 radio chip for the communication between the parking space sensors and the gateway node and the other is a GPRS modem for the communication between the gateway node and the central data server. The gateway node uses a rechargeable battery as its power supply, because the gateway node may be installed on a street lamp and directly uses the power from the street lamp. Unfortunately, the street lamp is frequently powered on only at night, and thus we designed a recharging circuit to charge the battery at night, and the battery will provide power supply to the gateway node in day time. The gateway node is

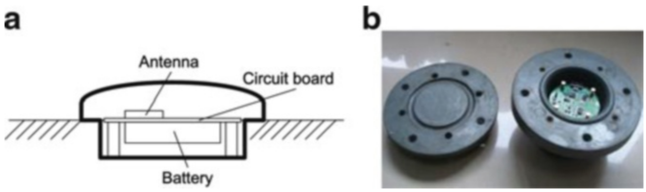


**Fig. 90.3** Parking space sensor. (**a**) Sensor design concept (**b**) The photo of the sensor

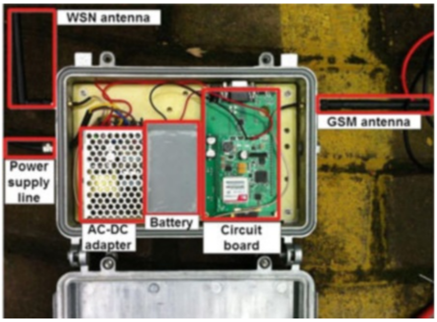


**Fig. 90.4** Gateway node

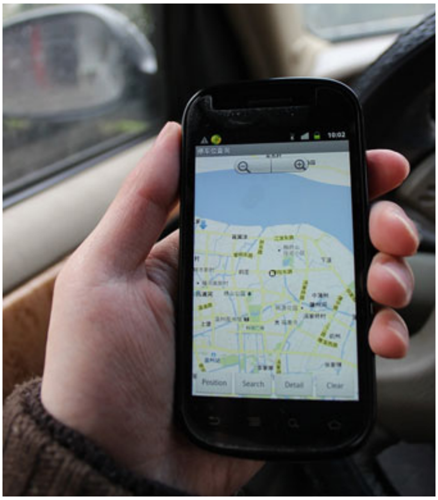


**Fig. 90.5** Parking guidance terminal

encapsulated in a water-resistant enclosure. The inner structure of a gateway node is given in Fig. 90.4.

*Parking guidance terminal*. The parking guidance terminal is built based on an Android smartphone, as shown in Fig. 90.5, in which the small circle on the screen indicates the current position of the car, and the blue arrow on the screen indicates the position of the detected available parking space. We used a Global Positioning System (GPS) receiver to mark the positions of parking spaces in system deployment. Because the position measuring error is only several meters, we believe that user experience will not be affected. The parking guidance terminal generally works as follows: (1) when a driver arrives at the destination, he just presses the "search" button on the screen; (2) the terminal communicates with the central data server to find nearby available parking spaces and then tells the driver; (3) the driver selects his favourite available parking space and the terminal will guide the driver to the chosen available parking space.

## 90.4 System Deployment and Evaluation

We have deployed an evaluation system covering about 12 parking spaces at a parking lot. Figure 90.6 shows the deployment of a parking space sensor and a gateway node. In deployment, we let parking space sensors transmit 100 packets in the TESTING interval and set the transmission success rate threshold to 80 %. Under these settings, parking space sensors typically spent no more than three working cycles to establish stable connections to gateway nodes.

Because of the extremely low active time of our parking space sensors after network joining, the battery lifetime can be extended to several years in deployment. We estimate parking space sensor's battery lifetime based on its typical working parameters. Table 90.1 gives the parameters.

We can estimate the battery lifetime ($T_B$) of parking space sensors according to (90.1), and the result is about 10.8 years.

$$T_B = W_B T_D / (I_A T_A + I_S (T_D - T_A)) \tag{90.1}$$

**Fig. 90.6** System deployment


**Table 90.1** Typical working parameters of parking space sensors

| Item | Value |
|---|---|
| Active current ($I_A$) | 40 [mA] |
| Maximum active time ($T_A$) | 0.05 [s] |
| Sleep current ($I_S$) | 0.03 [mA] |
| Working cycle ($T_D$) | 60 [s] |
| Battery capacity ($W_B$) | 6000 [mAh] |

## 90.5 Conclusion

In this chapter, we focused on the network design of a low-power parking guidance system. We developed a tiered communication architecture including WSN, GPRS network and Internet, and thus the deployment complexity can be greatly reduced. In order to maximize the battery lifetime of parking space sensors to reduce battery replacement costs in system maintenance, we designed a power-minimized TDMA-based MAC protocol for the WSN. Experimental results showed that the proposed MAC protocol can extend the battery lifetime of parking space sensors to more than 10 years.

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